TABLE 2.—*Tabulated data of sounding-balloon observations*—Con.

ST. LOUIS, MO.—Continued

Launched 8:07 a.m. Jan. 7, 1930 (75th mer.)—Continued

Time interval from launching	Altitude, M.S.L.	Pressure	Temperature	$\frac{\Delta t}{100 \text{ m.}}$	Humidity: Relative	Humidity: Vapor pressure	Wind: Direction	Wind: Velocity	Remarks
m. s.	*M.*	*Mb.*	*°C.*		*Pct.*	*Mb.*		*M.p.s.*	
	10,000	254.0	−62.4						
	11,000	215.0	−68.5						
50 08	11,810	189.0	−73.3	0.60					Tropopause.
	12,000	182.0	−73.6						
54 17	12,630	164.0	−74.4	.13					
	13,000	154.0	−73.4						
59 11	13,810	134.0	−71.2	−.27					
	14,000	130.0	−71.3						
	15,000	110.0	−71.7						
	16,000	92.0	−72.1						
68 49	16,340	87.0	−72.2	.04					
	17,000	78.0	−72.3						
75 02	17,910	67.0	−72.5	.02					
	18,000	66.0	−72.3						
	19,000	56.0	−70.7						
	20,000	47.0	−69.2						
83 08	20,400	44.0	−68.5	−.16					
	21,000	40.0	−67.4						
	22,000	34.0	−65.6						
88 17	22,750	30.0	−64.2	−.18					

SIOUX CITY, IOWA

Launched 8:03 a.m. Jan. 7, 1930 (75th mer.)

Time interval from launching	Altitude, M.S.L.	Pressure	Temperature	$\frac{\Delta t}{100 \text{ m.}}$	Humidity: Relative	Humidity: Vapor pressure	Wind: Direction	Wind: Velocity	Remarks
0 00	361	986.8	−20.4		49	0.49	nw.	4.0	1 A. St., SW.
	500	969.0	−22.2		49	.41			
	1,000	904.0	−27.3		50	.25			
2 38	1,070	896.0	−28.2	1.10	50	.23			Superadiabatic.
	1,500	843.0	−16.4		49	.72			
5 25	1,760	815.0	−8.9	−2.80	48	1.38			Inversion.
	2,000	791.0	−9.0		48	1.37			
7 26	2,300	758.0	−9.1	.04	48	1.36			Isothermal.
	2,500	738.0	−10.4		47	1.19			
	3,000	691.0	−13.2		47	.93			
	4,000	604.0	−19.1		47	.54			
16 56	4,600	559.0	−22.5	.58	46	.38			
	5,000	530.0	−25.8		48	.28			
	6,000	461.0	−34.1		51	.13			
26 12	6,160	449.0	−35.9	.86	52	.11			
	7,000	398.0	−41.6		52	.06			
35 48	7,890	348.0	−48.2	.71	52	.02			
	8,000	343.0	−48.8		51	.02			
	9,000	293.0	−55.5		50	.01			
45 38	9,640	266.0	−59.6	.65	49	[1]			Tropopause.
	10,000	252.0	−59.9		50	.01			
47 43	10,360	238.0	−60.2	.08	50	[1]			
	11,000	215.0	−59.4		51	.01			
51 52	11,350	203.0	−58.9	−.13	52	.01			
54 18	11,910	186.0	−54.9	−.71	52	.01			

[1] Less than 0.01 mb.

VICKSBURG, MISS.

(Launched 7:58 a.m., Jan. 7, 1930, 75th mer.)

Time interval from launching	Altitude, M.S.L.	Pressure	Temperature	$\frac{\Delta t}{100 \text{ m.}}$	Humidity: Relative	Humidity: Vapor pressure	Wind: Direction	Wind: Velocity	Remarks
0 00	92	1,009.0	17.1		86	16.78	se	4.0	10 Nb., SW.
	500	963.8	14.9						
	1,000	906.5	12.1						

TABLE 2.—*Tabulated data of sounding-balloon observations*—Con.

VICKSBURG, MISS.—Continued

(Launched 7:58 a.m., Jan. 7, 1930, 75th mer.)—Continued

Time interval from launching	Altitude, M.S.L.	Pressure	Temperature	$\frac{\Delta t}{100 \text{ m.}}$	Humidity: Relative	Humidity: Vapor pressure	Wind: Direction	Wind: Velocity	Remarks
m. s.	*M.*	*Mb.*	*°C.*		*Pct.*	*Mb.*		*M.p.s.*	
4 31	1,128	892.4	11.4	0.55					
5 17	1,303	874.0	12.0	−.34					Inversion.
	1,500	852.0	10.6						
	2,000	799.9	7.2						
	2,500	751.3	3.8						
	3,000	707.6	.3						
14 58	3,617	657.9	−3.9	.69					
	4,000	625.4	−6.5						
	5,000	550.8	−13.4						
25 00	5,434	520.4	−16.4	.69					
	6,000	483.5	−20.5						
	7,000	421.9	−27.8						
35 02	7,917	371.1	−34.5	.73					
	8,000	367.2	−35.5						
	9,000	317.5	−47.8						
	10,000	273.2	−60.0						
44 35	10,063	270.3	−60.8	1.23					Superadiabatic.
	11,000	233.0	−67.7						
49 00	11,307	221.8	−70.0	.74					Tropopause.
	12,000	198.9	−68.6						
	13,000	169.0	−66.5						
58 41	13,173	164.2	−66.1	−.21					
	14,000	143.7	−66.0						
	15,000	122.6	−65.9						
68 29	15,426	114.8	−65.9	−.01					
	16,000	104.7	−64.8						
78 35	16,759	92.8	−63.3	−.20					
	17,000	89.7	−62.8						
85 35	17,780	78.8	−61.0	−.23					

Launched 2:02 p.m. Jan. 7, 1930 (75th mer.)

Time interval from launching	Altitude, M.S.L.	Pressure	Temperature	$\frac{\Delta t}{100 \text{ m.}}$	Humidity: Relative	Humidity: Vapor pressure	Wind: Direction	Wind: Velocity	Remarks
0 00	92	1,007.7	20.2		83	19.66	s.	4.5	10 St., S.
	500	960.8	17.7						
	1,000	905.0	14.7						
	1,500	853.7	11.6						
7 26	1,672	836.9	10.6	0.61					
	2,000	804.5	10.4						
10 01	2,149	790.4	10.3	.06					Isothermal.
	2,500	756.5	7.8						
	3,000	712.4	4.3						
20 02	3,699	654.2	−.6	.70					
	4,000	625.9	−2.9						
	5,000	544.8	−10.4						
30 01	5,481	521.2	−14.0	.75					
	6,000	478.5	−17.3						
	7,000	424.4	−23.7						
39 40	7,295	409.5	−25.6	.64					
	8,000	372.5	−31.2						
	9,000	325.0	−39.1						
49 04	9,174	315.0	−40.5	.79					
	10,000	277.7	−48.6						
56 56	10,914	243.1	−57.5	.98					Adiabatic.
	11,000	239.3	−57.8						
60 10	11,540	221.1	−60.0	.40					Tropopause.
	12,000	206.1	−60.5						
	13,000	177.3	−61.4						
	14,000	150.6	−62.4						
75 23	14,089	148.5	−62.5	.10					

SNOW-SURFACE TEMPERATURE

By ROBERT E. HORTON and H. R. LEACH

[Consulting Engineers, Voorheesville, N.Y., Apr. 19, 1934]

(All temperatures in this paper are in Fahrenheit degrees)

On the polar ice shields, on glacier surfaces generally, and above the snow line in mountains, water losses, other than evaporation from snow or ice surfaces, are in general either nil or negligible. Available data on evaporation from snow indicate that it follows the same laws as evaporation from water surfaces if the difference in maximum vapor pressure over ice surfaces is taken into account. The conditions governing evaporation from broad snow surfaces differ from those for water or ground surfaces because the temperature of the latter follows the air temperature closely, with a difference commonly limited to a few degrees and dependent on latitude and elevation. The temperature of a snow or ice surface cannot rise above 32° F. The temperature of the evaporating surface governs the rate of vapor emission. As a result daytime evaporation from snow may be much less than would take place from an unfrozen surface at the same air temperature.

In studying evaporation losses for high latitudes and elevations it becomes important to determine the mean snow surface temperature. There are few data available on this point. Some of those available have been taken by exposing thermometers directly on the snow surface. The cold winter of 1934 at our place, Voorheesville, N.Y., afforded us a favorable opportunity for determining snow-surface temperatures. For this purpose maximum and minimum thermometers were exposed where the snow received full insulation, the entire thermometer being covered with not over one-half inch of snow. Standard Weather Bureau maximum and minimum thermometers were used. It was thought necessary to cover the thermometers to a slight depth because these instruments absorb and radiate heat more readily than the snow surface. In order to compare the results so obtained with those obtained elsewhere from thermometers exposed directly on the snow surface, additional instruments, exposed in the latter manner, were also used. The results of the observations taken with the two sets of instruments are shown on figure 1.

It will be noted that the maximum temperatures shown by the covered thermometer were always precisely 32° when the maximum air temperature, taken in the instrument shelter, was above 32°. The maximum temperatures shown by the thermometer exposed on the snow surface on the same days was always above—sometimes several degrees above—32°. In order to determine which of these series of observations most nearly represents the true surface temperature, additional observations were taken at hourly intervals during one entire day, using a standard Green test thermometer calibrated to ⅕°, readings being taken at hourly intervals. With this extremely sensitive thin-bulb thermometer the snow-surface temperature could be obtained quickly and accurately by laying the thermometer in the surface snow with the bulb barely covered. These observations are shown on figure 2.

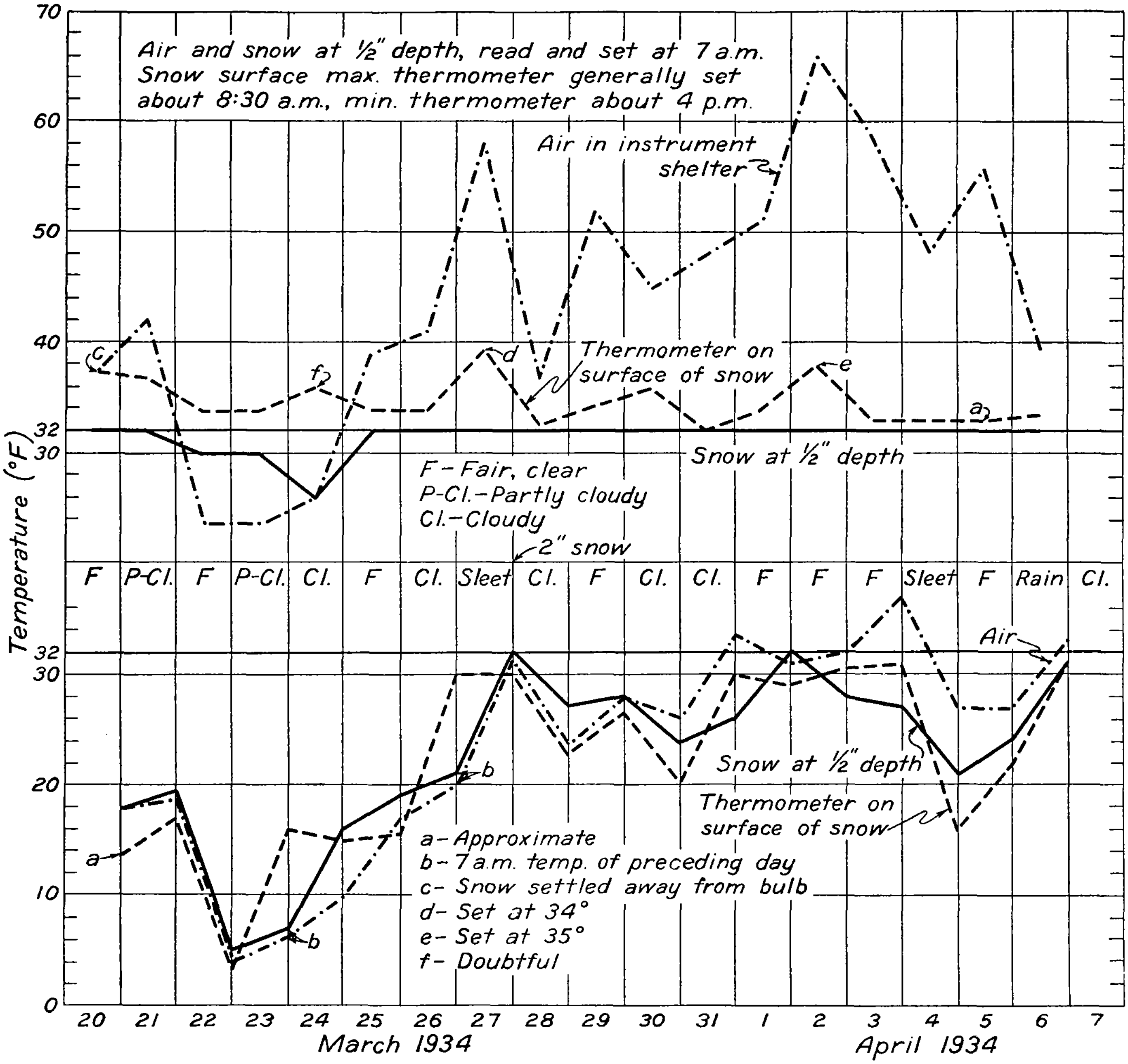

FIGURE 1.—Maximum and minimum air and snow temperatures at Horton Hydrologic Laboratory, Voorheesville, N.Y.

At the start, the air in the instrument shelter was 30.5°, rising later above 32°. The air in the open was above 32°. The snow-surface temperature started at 32° and rose to a maximum of 32.7°. The snow was light and newly fallen and about 90 percent of the volume consisted of air. Under these conditions the temperature near the surface of the air-snow mass can apparently rise a fraction of a degree above 32°. As far as the authors are aware this is the first time this phenomenon has been recorded.

Referring to figure 1 it will be noted that the minimum temperatures taken with a thermometer laid on the snow surface are in general a few degrees below the minimum air temperatures in the instrument shelter. Minimum temperatures taken with a covered thermometer are usually higher but also slightly below the air temperature in the instrument shelter. Data for the whole period December 15, 1933, to April 9, 1934, are not shown on the diagram.

When the air temperature is below 32° the temperature of the air in the shade and that of a snow surface are not necessarily equal—in fact, differences are to be expected: (1) When the sun is shining, because the snow surface and the air above the snow are then exposed to direct insolation, whereas the air in the shelter is not; (2) at night the snow surface is exposed to direct radiation but if the air temperature is well below 32°, the surface of a deep layer of snow may apparently be considerably heated by conduction from below. The temperature within a deep snow layer with steady air conditions is generally close to 32° at the ground surface. Snow-temperature gradients taken by the senior author showed at times a temperature increase from the surface downward as great as 10° F. per foot depth.[1] Such a temperature gradient is conducive to an upward flow of heat tending to warm the snow surface.

face, 22.1°. For the 109 days of observations when the minimum air temperature did not exceed 32°, its average value was 8.7° and the average minimum temperature of the snow ½-inch below surface on the same days was 13.3°. Taken as a whole, the data indicate that snow surface temperatures when the air temperature is below 32° are, on the average, 3° to 4° higher than the air temperature. The observations were taken at latitude 42°40′ N., longitude 73°55′ W., and 300 feet above sea level. It is probable that the difference between air temperature and snow-surface temperature is a function of latitude and elevation, as has been found to be the case for difference between water and air temperatures.

As snow temperatures generally increase downward when the air temperature is below 32°, the covering of the snow theremometer to a depth not exceeding ½-inch would apparently tend to give somewhat too high minimum temperatures. Observations of snow temperature gradients cited above indicate that the observed minimum snow temperatures are not likely to be as much as ½° F. too high on this account.

The normal diurnal air temperature curve in fair weather is a combination of a sine curve and a radiation

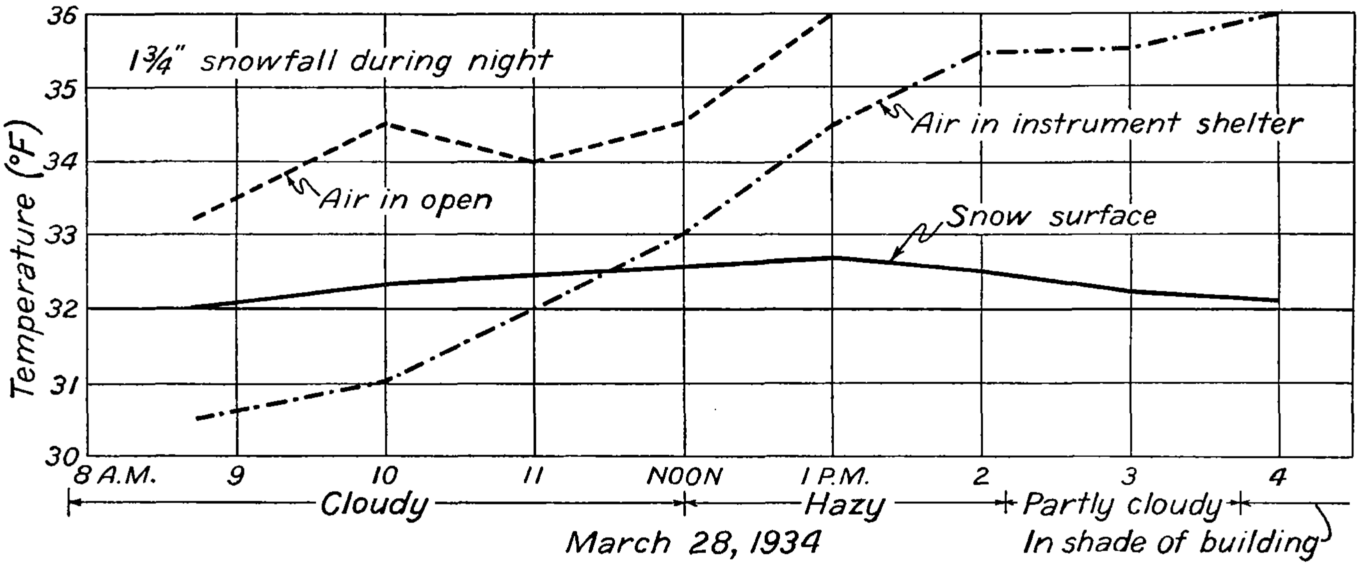

FIGURE 2.—Hourly observations of snow-surface temperature at Horton Hydrologic Laboratory, Voorheesville, N.Y.

The effects described would tend to make the snow-surface maximum temperature and the snow-surface minimum temperature both greater than the air-maximum and minimum temperatures.

The observations indicate that snow temperatures taken with thermometers exposed on the snow surface give too high maximum and too low minimum temperatures. The snow-surface temperature is 32° when the air temperature is higher and a thermometer covered with not to exceed half an inch of snow gives a sensibly accurate measure of the maximum snow-surface temperature.

For the period of 15 days when observations were taken both with thermometers on the snow surface and at ½-inch depth, the average minimum temperature at ½-inch depth in snow was 21.4° and the average minimum temperature in the instrument shelter was the same. The average minimum temperature shown by the thermometer exposed on the snow surface for the same days was 20.5° or nearly 1° lower. For the entire period covered by the observations, taking first the maximum temperatures on the 57 days when the air temperature did not exceed 32°, the average maximum air temperature was 18.7° and the average maximum snow temperature ½-inch below sur-

or exhaustion curve. The diurnal temperature graph may be approximately represented by a triangle with the apex at the maximum and the base connecting 2 minima. The fraction of the day, if any, during which the air temperature is 32°, is nearly proportional to the ratio of the difference between the maximum and 32° to the difference between the maximum and minmuim temperature. On this basis an approximate formula for determining the mean-snow-surface temperature on days when the maximum thermometer is above and the minimum below 32° can readily be obtained from geometrical considerations, as follows:

$$\theta_s = 32\frac{\theta_a - 32}{\theta_a - \theta_i} + \frac{32 - \theta_i}{\theta_a - \theta_i}\left[\frac{32 + (\theta_i + \Delta)}{2}\right]$$

in which θ_a is the maximum, θ_i the minimum, and θ_s the mean daily snow-surface temperature. Δ is the difference between the air and snow-surface minimum temperatures. From the preceding experiments, allowing for the effect of ½-inch submergence of the thermometer, the value of Δ is apparently $+4°$. For $\theta_a = 44°$ F., $\theta_i = 24°$ F., the mean snow-surface temperature would be 31.2° F., or slightly below freezing, although the mean-air temperature for the day was 34° F. It is hoped that values of Δ at other locations will be obtained and published.

[1] Horton, Robert E. The melting of snow; MONTHLY WEATHER REVIEW, December 1915, v. 43, pp. 599–605.